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USAARL REPORT NO. 72-11

HELICOPTER IN-FLIGHT MONITORING SYSTEM

By

HARLIE W. HUFFMAN
MARK A. HOFMANN
MICHAEL R. SLEETER

MARCH 1972

U. S. ARMY AEROMEDICAL RESEARCH LABORATORY

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ABSTRACT

This paper deals with the description of a helicopter in-flight monitoring system. This system measures and records in real time, all six degrees of freedom of the aircraft, cyclic, collective, and pedal inputs as well as some status values.

APPROVED: Robert W. Bailey
ROBERT W. BAILEY
COL, MSC
Commanding

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INTRODUCTION

The increased use of the helicopter in combat and commercial environments has precipitated many questions with regard to factors affecting the performance of rotary wing aviators. Requisite to determining these factors and their affects is the requirement to measure precisely aviator control inputs and monitor subsequent aircraft responses to these inputs.

The United States Army Aeromedical Research Laboratory, in an effort to determine such variables and their affects, instrumented a JUH-1H helicopter to measure pilot input and monitor the aircraft position, rates and accelerations. The helicopter in-flight monitoring system (HIMS) measures the aircraft in all six degrees of freedom while simultaneously recording cyclic, collective and pedal inputs as well as some status values. All measurements are recorded in real time on an incremental digital recorder. The recorded values are then reduced and analyzed on ground based digital computers. This paper deals with a brief description of the transducers, signal generators and recording system which constitute the HIMS. A Flow Chart (Figure 1) shows the basic relationship between the various subsystems.

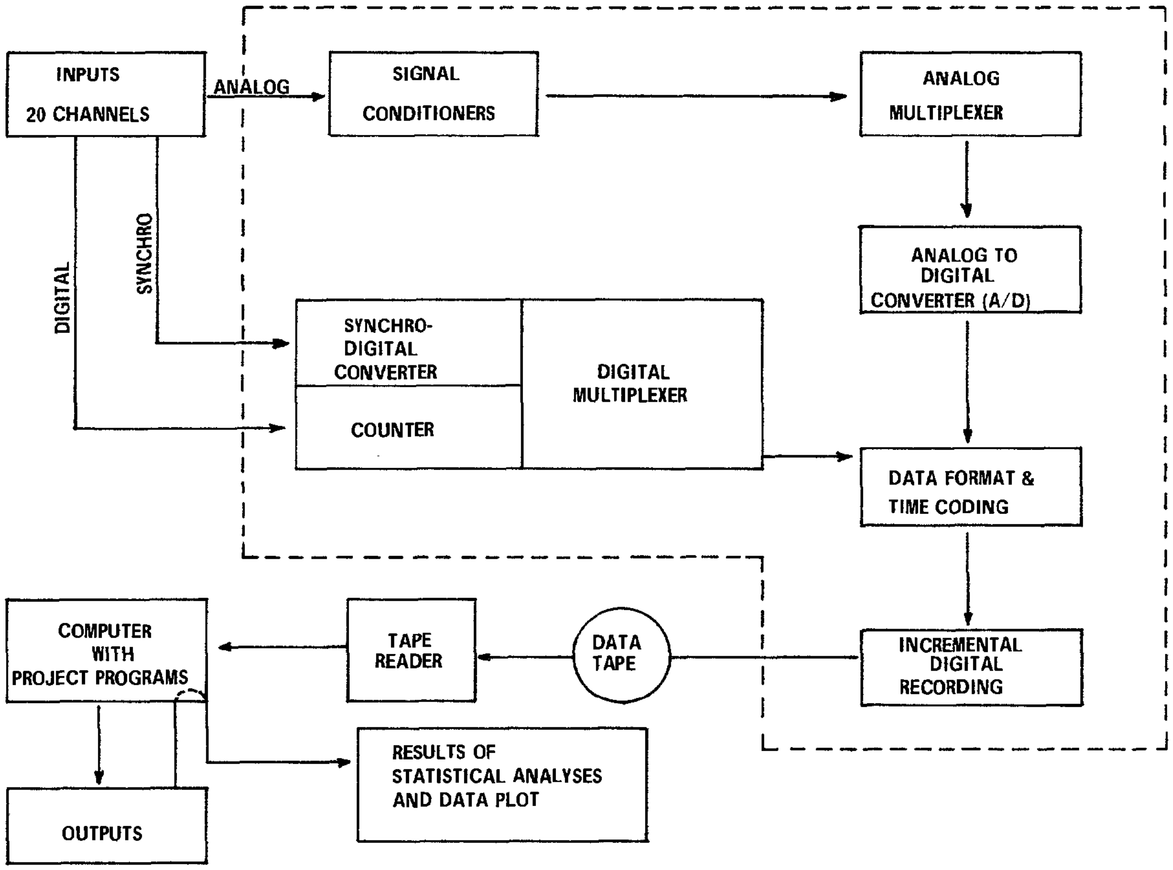


Figure 1

Flow Chart

LINEAR MEASUREMENTS

A. Airspeed

Airspeed is obtained from a differential pressure transducer that is connected directly to the aircraft's pitot and static lines. It has an output voltage (0-5 volts), which is obtainable from an infinite resolution carbon-film potentiometer. The potentiometer's multiple wipers are coupled directly to the pressure capsule in order to minimize its sensitivity to vibration, shock and temperature, while maximizing its repeatability and reliability.

The pressure range is 0-1 PSI and the output resistance is 5,000 ohms. The dynamic error band is ± 0.6 percent of full scale voltage. Temperature sensitivity is ± 0.01 percent/degree Centigrade and the response time is 20 milliseconds to respond to 63 percent of step pressure input. Size (less fittings) is approximately three inches in diameter by three inches high and weighs ten ounces.

The output of this transducer is calibrated to the aircraft's airspeed indicator to yield airspeeds consonant with those indicated to the pilot.

B. Altitude

Altitude is obtained in two ways: a barometric altitude, referenced to sea level is obtained from a pressure transducer with a response and resolution similar to the altimeter that the pilot uses. More accurate position of the aircraft's height above ground is provided by a radar altimeter.

1. Barometric Altitude

The altitude transducer is connected to the aircraft's static line and is capable of providing altitude information from 0-10,000 feet. It, like the airspeed transducer, has an output potentiometer with an infinite resolution, carbon-film, 0-5,000 ohm element. Its effective resolution is five feet with a repeatability of 15 feet. The allowable dynamic error band is 0.54% of full scale voltage and the total error band (with light vibration) is 45 feet. The response time is 20 milliseconds to respond to 63% of a step pressure input.

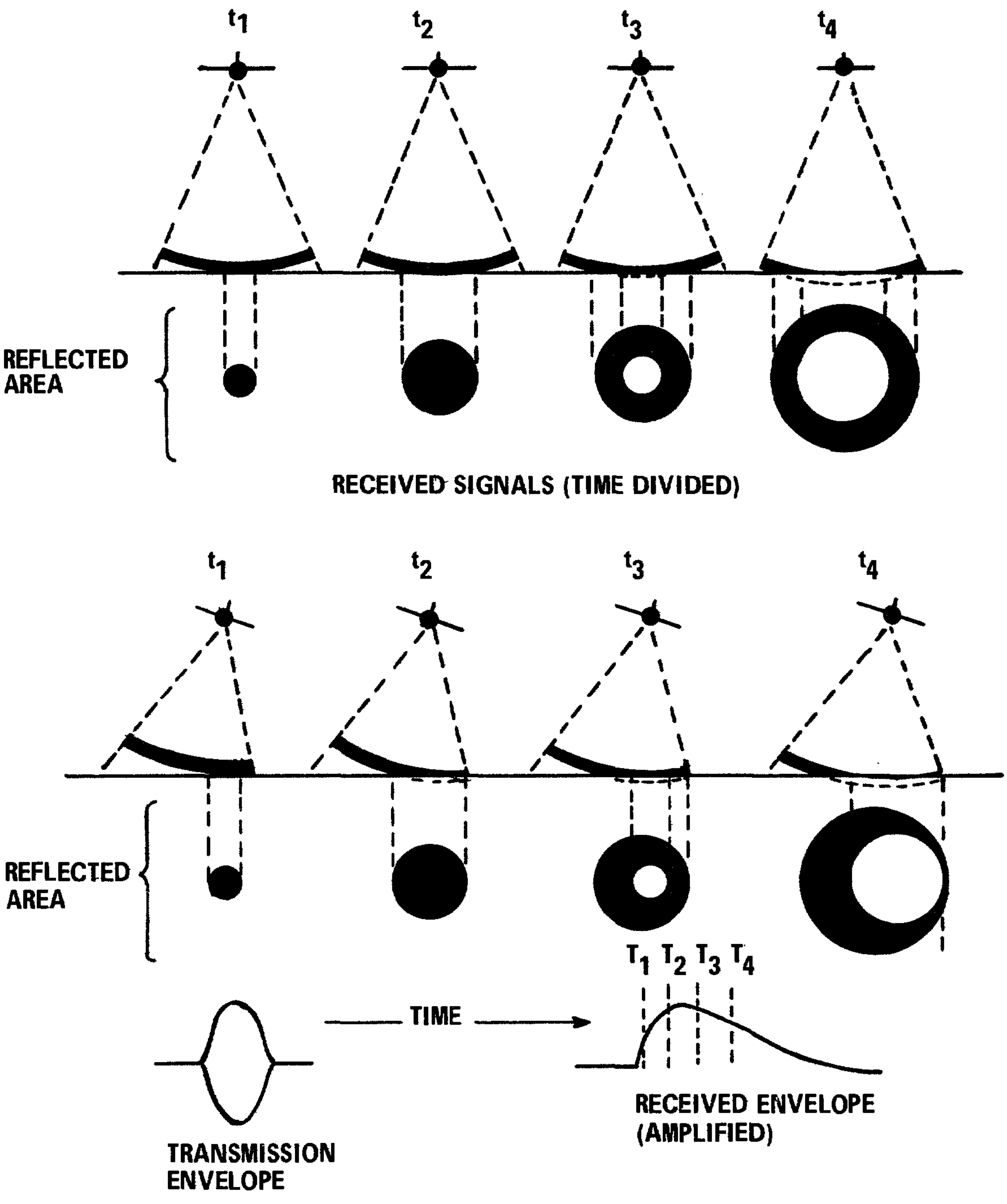
As was the case with airspeed, the output of this tranducer is calibrated to the aircraft's altimeter so the recorded values will comply with those altitudes seen by the pilot. Errors are reduced by recording the static output of the transducer before each flight, along with the barometric pressure and temperature. These values are then used in the computation of altitude during data reduction.

2. Radar Altitude

A radar altimeter is used to get accurate altitude above the terrain. It is a high resolution pulse radar device operating in the 4300 mc. frequency band. It measures the time (analogous to distance) required for a pulse of electromagnetic energy to travel from the aircraft to the ground and back. An RF pulse with a minimum peak power of 50 watts and a pulse width of 35 nanoseconds is used for altitudes of 0 to 1000 feet. At approximately 1000 feet of altitude the RF pulse width is switched to 125 nanoseconds, by a pulse-width switching circuit in the modulator and the peak power is increased to a minimum of 100 watts. The tracker detects the leading edge of the reflected signal and after lock-on rejects all other signals until the next pulse is received. The time of pulse arrival is compared with the time of pulse transmission and the resultant time differential is processed to provide the range information in an analog form.

The computing circuitry permits altitude measurement to touchdown. This is accomplished by providing sufficient electromagnetic isolation between the transmitter and receiver modules which permits acceptance of early reflections from the ground, while the transmitter pulse is still being radiated.

The need for leading-edge tracking originates in the requirement for accurate altitude information. This type of signal processing offers the most easily mechanized concept for pulsed emission, because the entire surface of the ground, within the transmitted beam, does not necessarily contribute to increasing the peak power to the receiver. It may only increase the pulse length received. The leading edge of the return consists of the integral of the earliest return originating from the area relatively close to the vertical incidence vector. Therefore, the leading edge is quite consistent and occurs at a time representative of the nearest reflecting object (see Figure 2). This method of closed-loop, leading edge, tracking eliminates multiple path errors due to reflections from rotor blades at low altitudes. The antenna beam width permits maneuvering up to ± 35° in pitch or roll while maintaining accurate altitude information.



RECEIVED SIGNALS (ROLL ATTITUDE)

Figure 2

Radar Altitude Signals

It was found that if the signal ground from the radar altimeter was connected directly to the signal ground in the recorder, it created voltage offsets and noise on the other information channels. To eliminate this, an isolation amplifier was used (see Figure 3). It contained an I.C. 741 differential amplifier employed in the non-inverting mode with feedback to produce unity gain. It was powered from the ± 15 volt supplies for the filters which have grounds referenced to the signal ground of the recorder inputs. The amplifier's zero adjust is used to calibrate the radar signal to 0 when the aircraft is on the ground and a 5,000 ohm trim-pot is used for calibrating the input to the recorder to + 5 volts at 5,000 feet altitude.

The range accuracy of the altimeter is ± 3 feet and 3 percent of range and its track rate capability is ± 2,000 feet per second. The volume occupied is 160 cubic inches and it weighs 7.5 pounds. The power requirement is 28 volts at 35 watts.

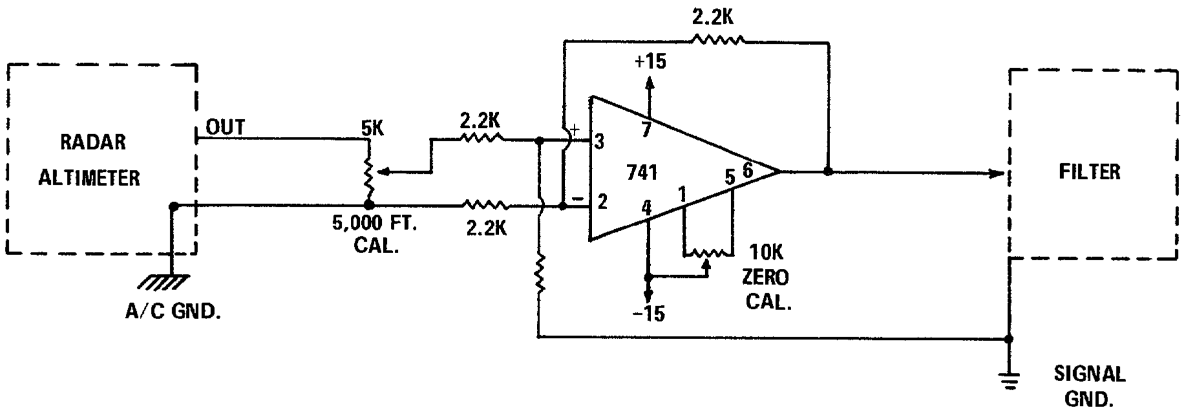


Figure 3

Radar Altitude Amplifier

C. Linear Acceleration

A hermetically sealed triaxial accelerometer with 5,000 ohm potentiometer outputs was used. These accelerometers have an accuracy (including linearity and hysteresis) of ± 1 percent of full scale at zero G's increasing to ± 2 percent of full scale at maximum. These accelerometers have a full scale range of ± 5 G's and have a 22 cps natural frequency with damping of 0.7 ± .2 of critical. They weigh approximately six ounces.

The output potentiometers are energized by regulated + 5 volts from the transducer power supply located in the filter chassis. Their outputs are fed through low pass active filters which roll-off at 2 cps. These filters were selected to eliminate, from the signals, a prevelant six-cycle vibration found to exist in the helicopter. Output from the filters are fed to the analog multiplexer inputs for sampling and recording.

The triaxial accelerometer (approximately 1" high by 1.6" wide by 2" long) can be aligned and mounted on the frame of the aircraft in the area in which the accelerations are to be measured.

Calibration was performed on a laboratory calibrator vibration table.

D. Aircraft Position

The aircraft position is obtained by a radio location system which currently covers approximately 100 square miles. This system consists basically of four ground stations and one portable airborne navigator which is a receiver and comparator. The ground stations are divided into two sets. Each contains a continuous wave transmitter and a single side band station.

This system determines distance by means of the phase comparison of continuous-wave radio signals. The phase comparison, however, takes place at an audio frequency, thereby eliminating the problems of phase comparison at radio frequencies, yet retaining a high degree of sensitivity. This process is accomplished by the use of two continuous-wave, unmodulated transmitters operating on a pair of frequencies which are harmonically related so that the harmonic of the lower frequency differs from the higher frequency by a known audio amount.

The continuous wave transmitter, "A" generates a carrier of about 3.2 mhz. This signal is received in the Navigator and is used for reference (see Figure 4). It is also received by the side band station "B" and mixed with a frequency generated internally

which is

$$2X\,\frac{FM + a}{2}.$$

This yields an audio frequency near 450 hz which is transmitted on the side band. The carrier from the side band station is

$$\frac{FM + a}{2}$$

and is received by the Navigator. The carrier frequency is doubled and mixed with the one from the CW station which generates a heterodyned 450 hz signal which is phase compared with the 450 hz from the side band station. The signals are fed through constant amplitude amplifiers in the phase meters and used to drive a null seeking servo motor which is geared to the position counters (dials) and a photo-electric encoder disc for electrical outputs. The other position "D-C" is identical in operation but different frequencies are used.

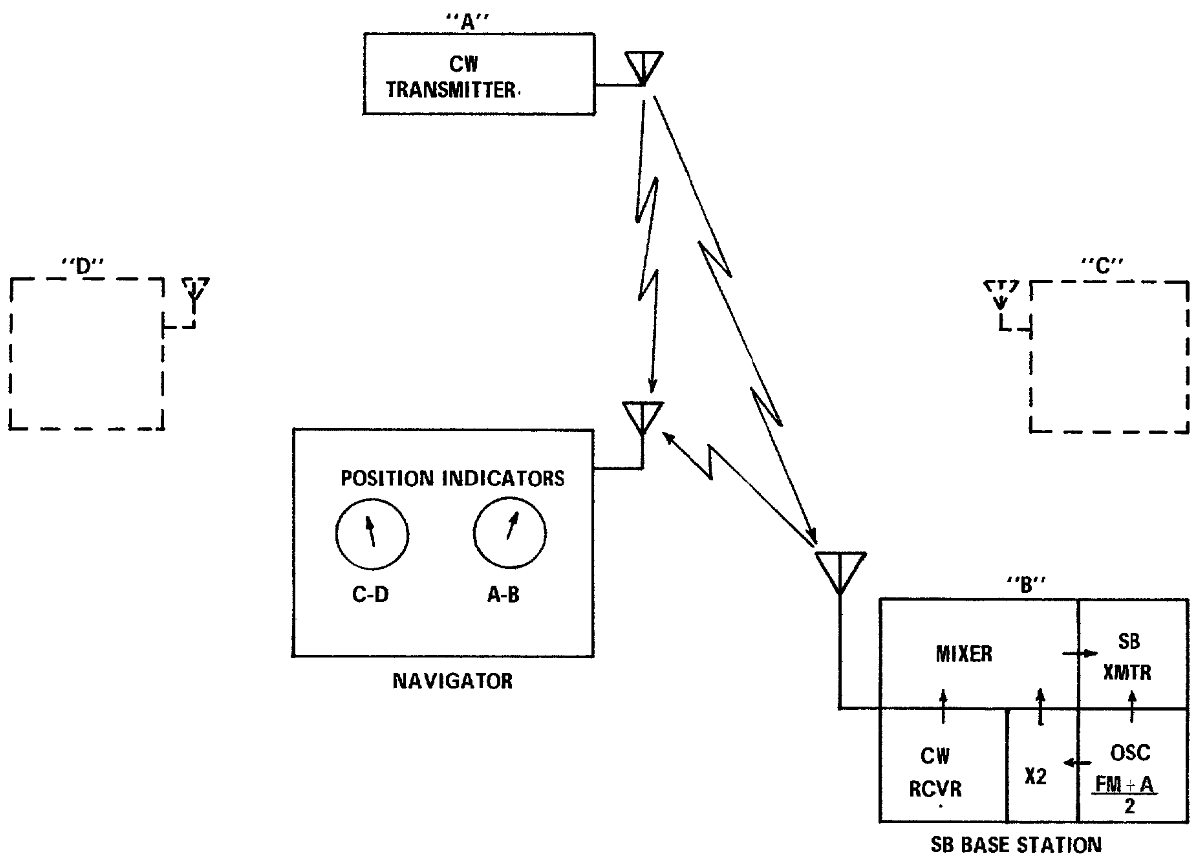


Figure 4

Positioning System

The output encoders consist of two photo diodes, a long-life lamp, and a five-window shutter geared to the position indicator shaft. The output of the encoders are two square waves in quadrature, with each other. These are routed through a plug-in buffer amplifier to provide low impedance logic levels of 0 to + 12 volts which are transmitted to a digital up-down counter, the values of which are recorded. In its present configuration, there are 50 counts per lane, (one wavelength of the audio frequency) with each lane being 150 feet in width. There are a total of four output signal terminals. Two terminals provide the phase meter reference signals for the two sets of stations and the other two provide the quadrature signals to sense direction of rotation of the phase meters.

The continous wave transmitters deliver 65 watts of r-f power to their antennas. They are approximately 14" x 11" x 9" in size and weigh 21 pounds. The side band units put out 50 watts p.e.p. and are 9" x 12" x 17" in size and weigh 29 pounds. Fifty and 80 foot antennas are used for the ground stations (see Figures 5 and 6).

The Navigator is 13" x 12" x 15" and weighs 31 pounds. It is bolted to a flat metal base which has four legs. These legs are spaced the same as those in the jump seats which facilitate installation and removal of the Navigator (see Figure 7).

The Navigator uses two, 2 foot active antennas built of fiberglass for receiving the four signals from the ground stations. One antenna is mounted on the nose of the aircraft, the other is underneath the aircraft at the rear of the body (see Figure 8). Two antennas were employed to reduce the possibility of losing signals due to aircraft orientation.

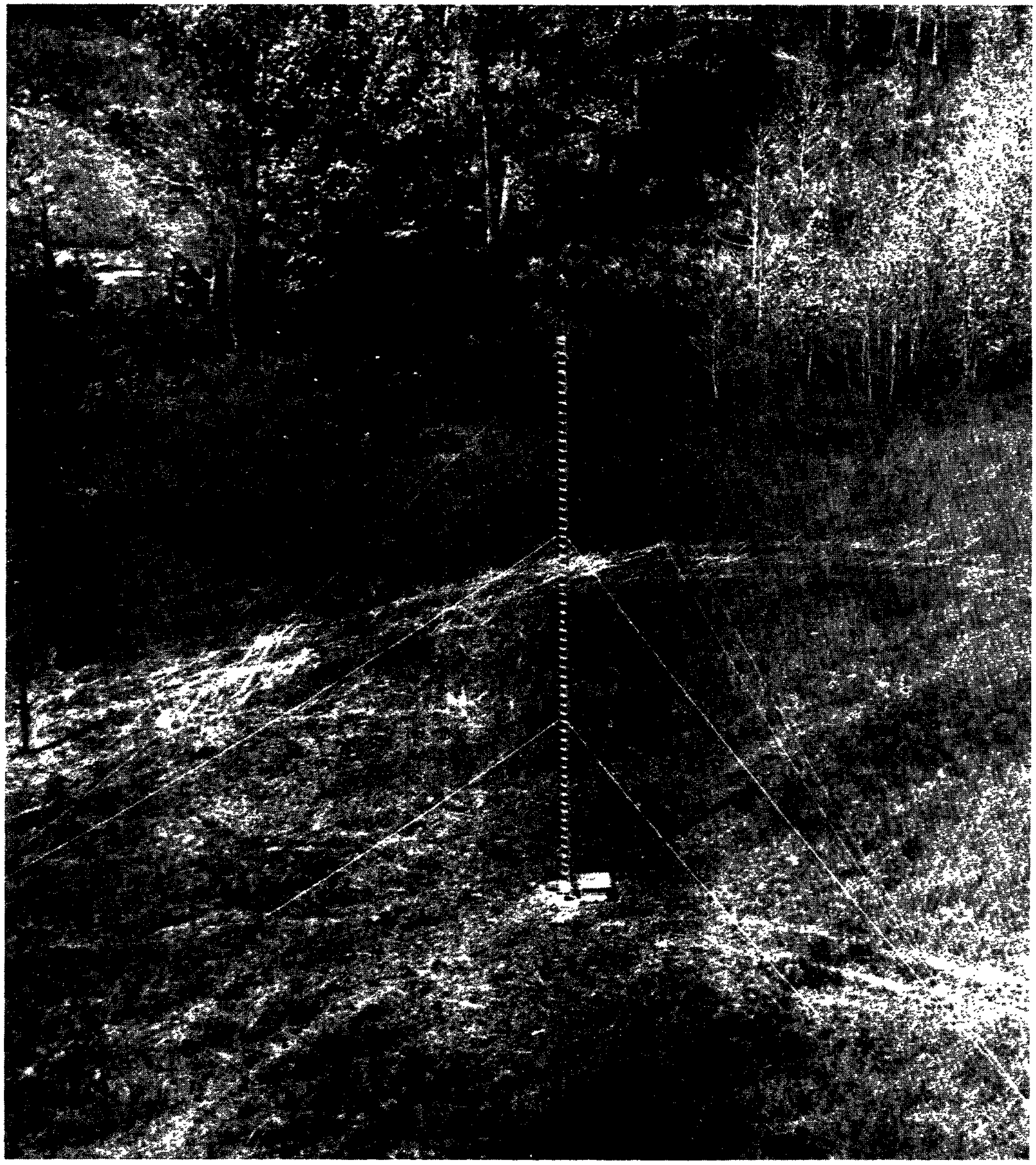


Figure 5

Ground Station

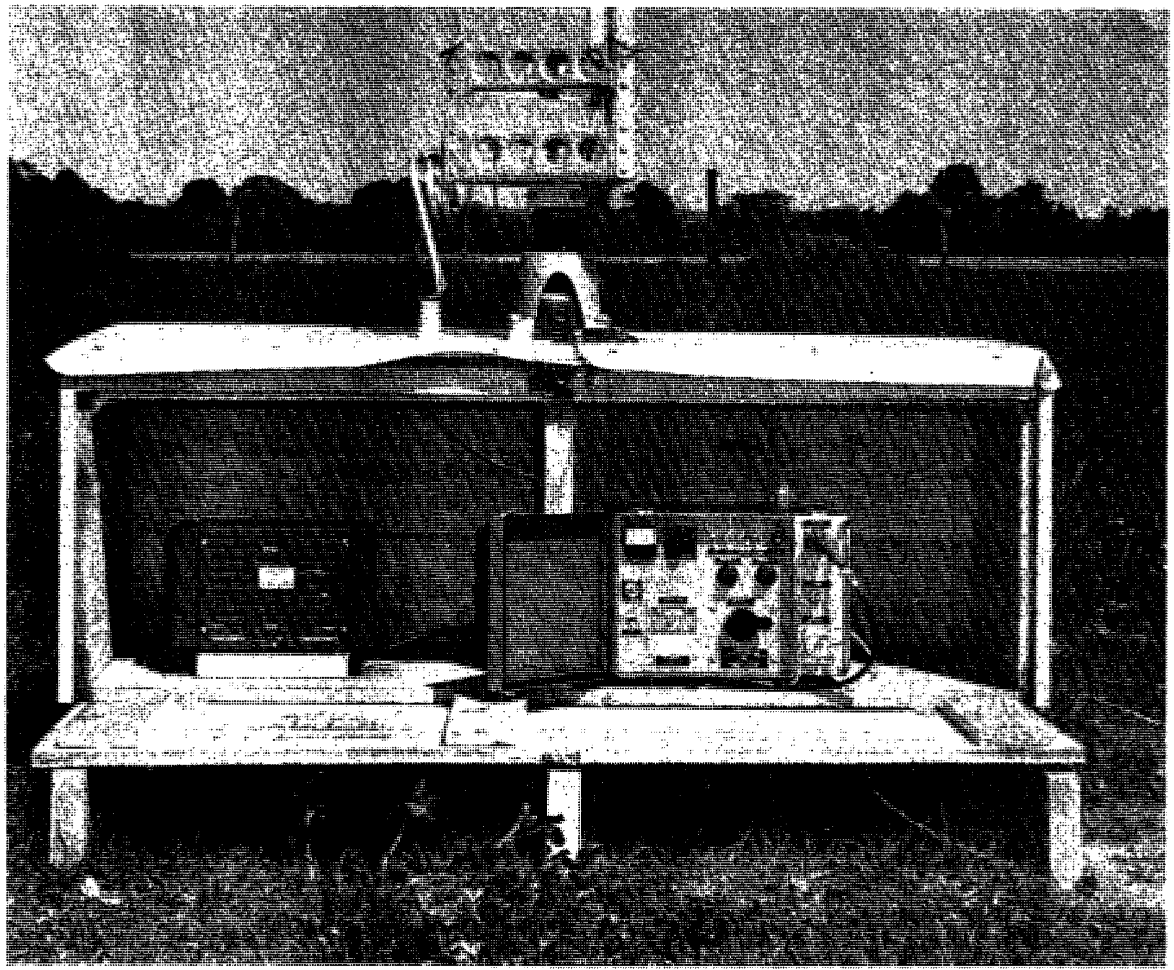


Figure 6

Ground Station

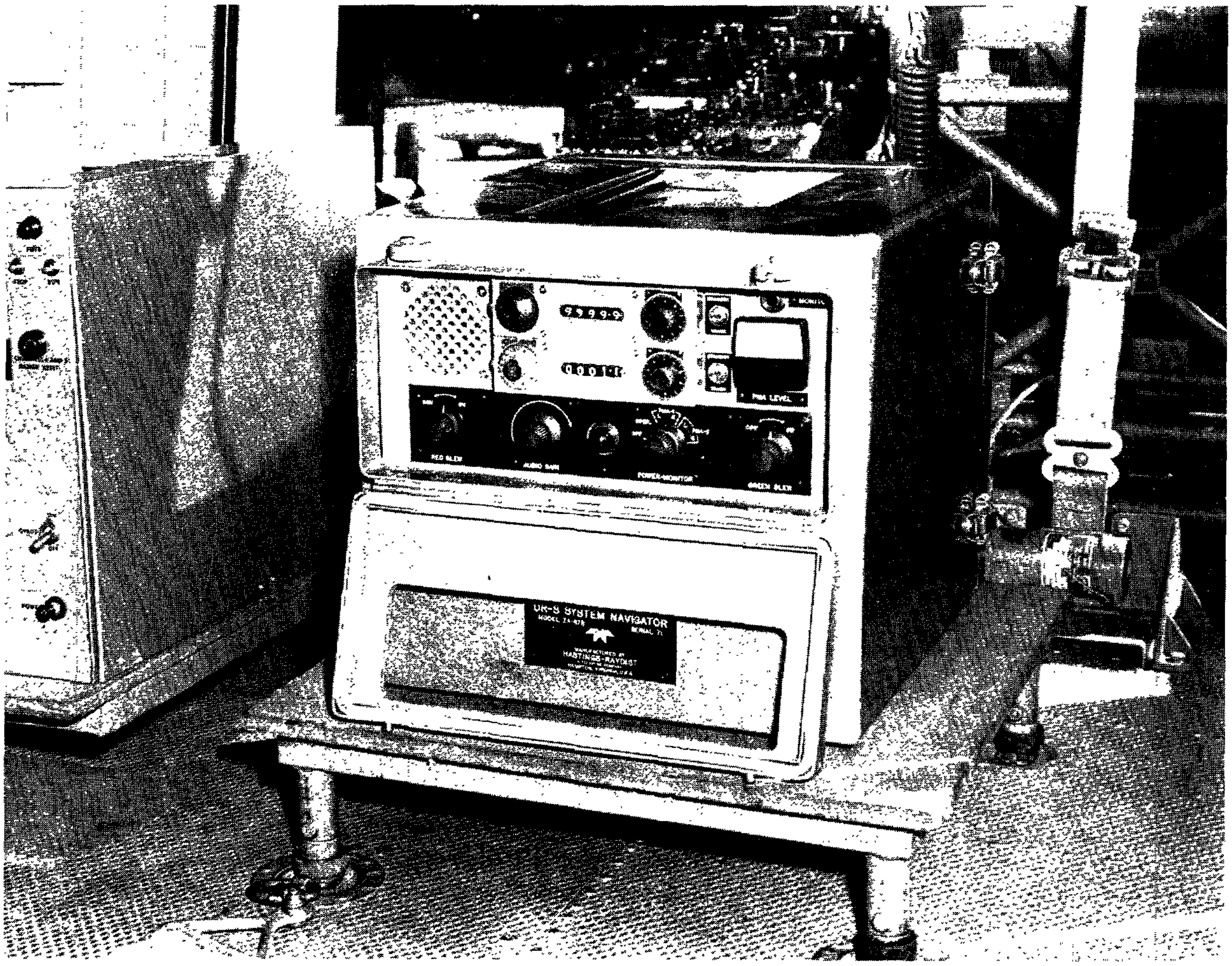


Figure 7

Navigator

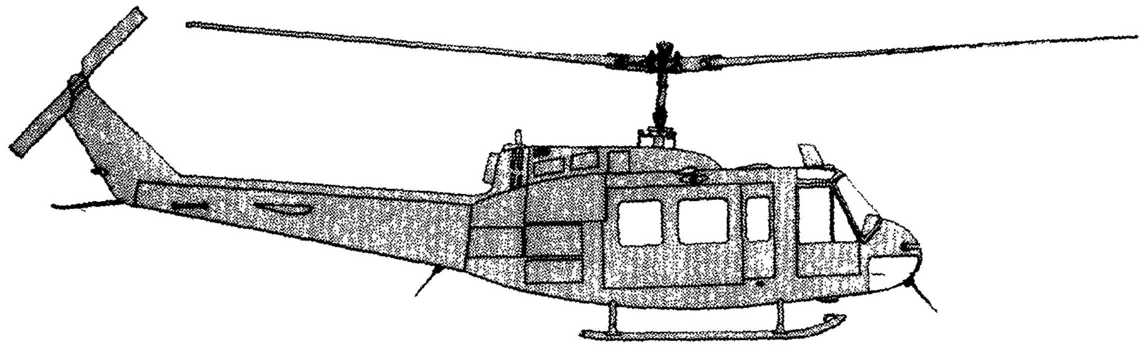


Figure 8

Position of Navigator Antennas

A. Pitch and Roll

The pitch and roll positioning information is recorded directly from the MD-1 Gyro in the aircraft that drives the pilot's attitude indicator. Thus, this information will directly correspond to the attitude information available to the pilot. The MD-1 is a single gyro with its spin axis stabilized in the vertical position. Two synchros, one on each gimbal of the gyro, have outputs proportional to pitch and roll. Theorectically, therefore, there would be no output from the pitch synchro if the nose of the aircraft moved laterally with respect to the earth while at a roll angle of 90°. However, due to the limited maneuverability of the aircraft, this presents no problem.

The rotors of the synchros are excited with 110 volt, 400 cycles from the ship's inverters and this voltage is used as the reference for the synchro-digital converters. The 3-lead output from the synchros are fed into the signal inputs of the converters, to be digitized and recorded. To keep the ship's wiring harness intact a break-out adapter was fabricated. It has mating male and female connectors identical to that on the MD-1 gyro so it could be inserted between the gyro and its connector. The outputs were then taken from this adapter and fed through shielded cables to the synchro-digital converter.

B. Heading

Heading information is obtained from the auxillary synchro transmitter, B308, found in the pilot's ID-998/ASN course indicator. This signal is slaved to the J-2 gyro compass by a servo amplifier and motor which drives the pilot's heading dial and the rotor of the synchro. The J-2 gyro is slaved to magnetic north by a flux valve located in the tail of the helicopter.

The three outputs from the synchro stator along with the 26 volt, 400 cycle rotor excitation (reference) voltages are fed via shielded wiring, to the heading synchro/digital converter. An adapter similar to the one used on the MD-1 gyro was used for the ID998 indicator in order to keep the ship's wiring intact.

C. Angular Rates

A triaxial mounted rate gyro is used to measure the instantaneous angular velocities corresponding to roll, pitch and yaw. Each rate gyro is a DC operated gimballess type with 5,000 ohm potentiometer output. Each has a full-scale range of ± 100 degrees/second, a natural frequency of 30 hz and a damping factor of .7 ± .2 of critical. The accuracy (including repeatability and hysteresis) is ± 1 percent of full scale at zero degrees/second increasing to ± 2 percent at maximum rate. The threshold is .5 percent of full scale. The gyro spin motors require 28 volts DC ± 10 percent at a running current of 300 ma. and a starting current of 2.5 amps maximum (starting time is approximately 15 seconds). The overall weight is approximately 3.5 pounds.

This velocity transducer is appropriately aligned and affixed to a firm structure of the aircraft at a convenient location. The 0-5 volts DC outputs from the potentiometers go through the five cycle low pass filters before entering the recorder.

Calibrations were made on a laboratory rate of turn table.

PILOT'S CONTROLS AND TRANSDUCERS

A. Collective, Pedal, Cyclic and Throttle

The transducers selected to obtain the position of the pilot's controls (collective, pedals, cyclic, and throttle) provide an output proportional to the linear movement of a stainless steel cable from a 5,000 ohm potentiometer. This cable is retracted by means of a constant tension spring motor which maintains even cable tension. Response acceleration rates up to 100 G's can be tolerated while maintaining a 1 percent resolution. The cable extensions were from 0-5 inches for pedals, cyclic, and throttle controls because their over-all linear travel was less than 4.5 inches. A 0-10 inch extension was used for the collective because it's movement was slightly over 7 inches.

Each transducer was mounted on the frame of the aircraft in line with the control rod of interest. For safety, the stainless steel cable of the transducers was connected to one to two inches of bead chain which was in turn soldered to a clamp that was placed around the control rods. The bead chain used was size #3 brass bead which has a tensil strength of 18 pounds. This method of connecting provided a positive (no play) connection and also a reliable break-away in the event of a mechanical malfunction in the transducer (see Figure 9).

Care was used in connecting the cables, so the transducers remained within their operating limits. They were extended to one-half their maximum travel and connected to the control rods which were also positioned at one-half their total travel.

The outputs are calibrated in percent of control movement. The minimum voltage ouput when the control is at one limit is zero percent and the maximum voltage output when the control is at the opposite limit is 100 percent.

Each transducer is energized with the regulated + 5 volts and the slider output fed through a five cycle filter and in turn routed to the analog multiplexer for sampling and recording.

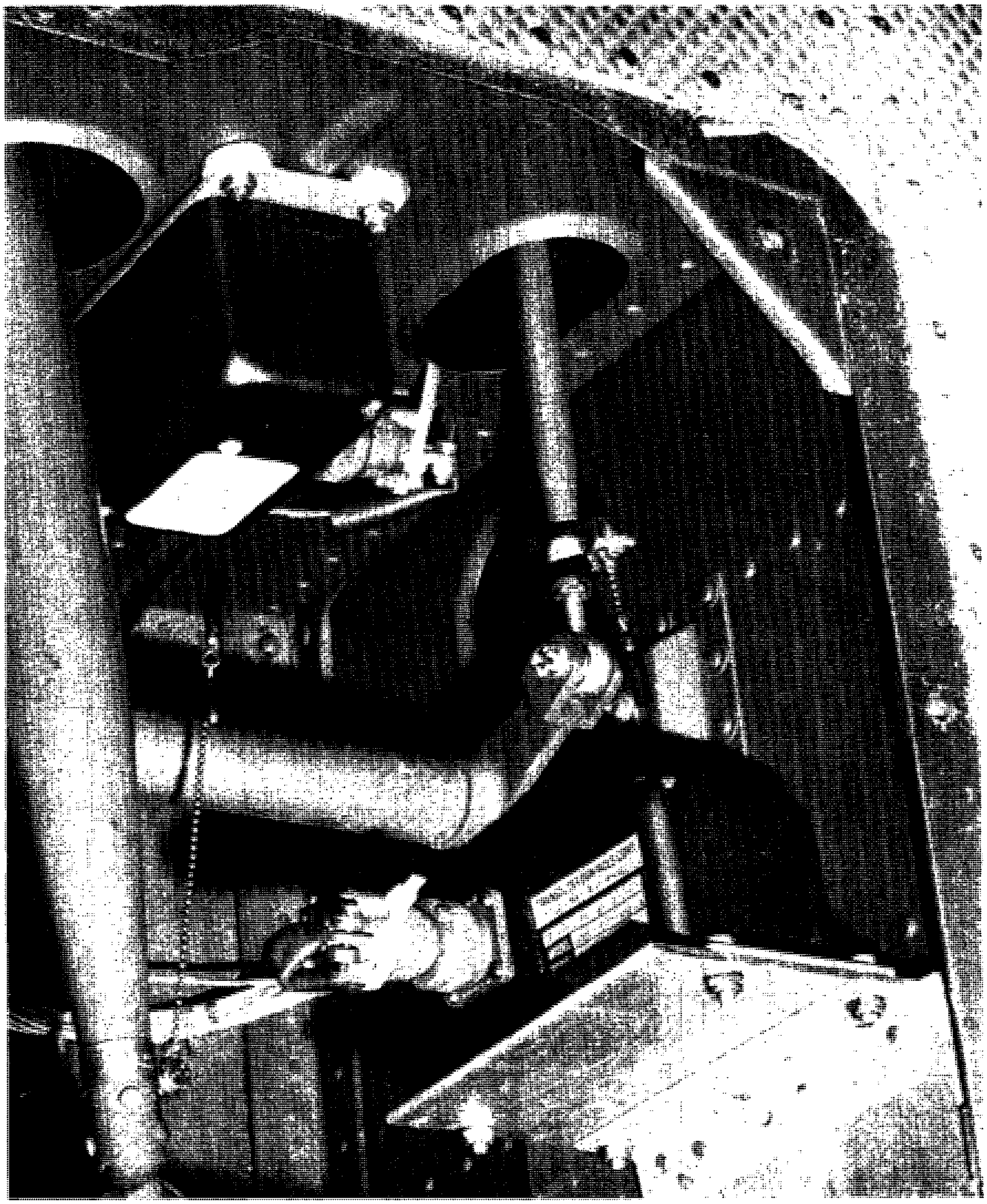


Figure 9

Control Transducers

B. Rotor RPM

This signal is obtained from the ship's tachometer. This tachometer is gear driven from the rotor shaft. It has a three phase alternating current voltage output which varies in amplitude and frequency as a function of shaft velocity. This AC voltage is converted to a 0-5 DC voltage by the circuit shown in Figure 10. Two 1500 ohm one-quarter watt input resisters were used for isolation to protect the circuit in case of malfunction. The 1N 457's rectify the AC which is then filtered by a 50 μf. capacitor. R1, R2 and R3 attenuate the DC voltage to 5 volts for maximum RPM. The output is adjusted by R3 (2K ohm trim-pot) to yield 1.5 volts per 100 RPM. This is fed to a five cycle filter before recording.

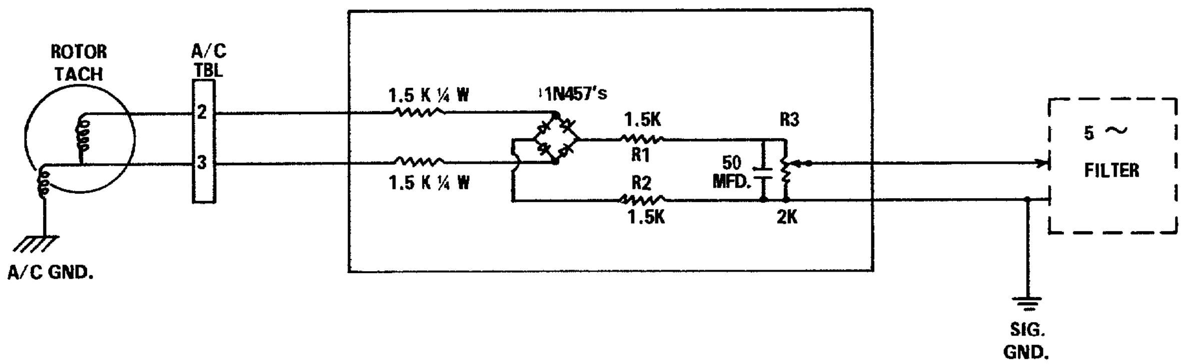


Figure 10

Rotor RPM Converter

A. Counters

The counters for aircraft position are triggered with logic level square waves produced by the encoder amplifiers. These waves are in quadrature with one serving as a reference and the other as the counting signal. Whether or not the counter counts is determined by a positive transition of the driving signal. Whether or not it counts up or counts down is determined by the voltage of the reference at the time of transition (see Figure 11). If the reference is zero at the time of transition (T_1, T_3), the counter counts up, if on the other hand, it is positive, the counter counts down. In order to eliminate any counting due to "jitter" in the phase meters (T_2), a logic circuit was installed that permits only one count per reference change. The counters track and hold the number of input signals which are recorded when strobed by the recorder formatter.

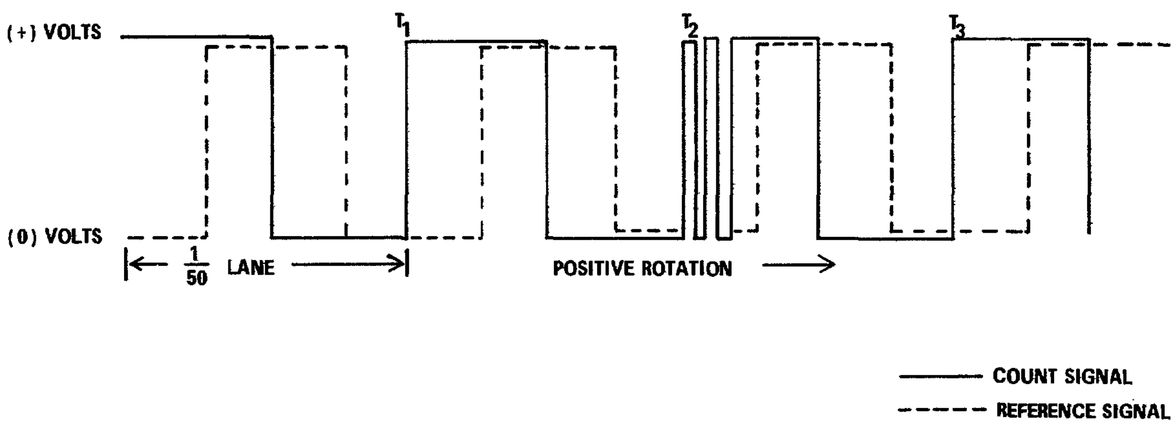


Figure 11

Encoder Output Waveform

B. Synchro/Digital Converters

Three channels of information, pitch, roll, and heading are obtained from the synchros found on the instruments of the aircraft. The converters used to digitize this information are encapsulated types with an accuracy of ± 4 minutes and a resolution of 14 bits. They track at a rate of 0 to 360°/second with full accuracy. The synchro data is continuously converted to digital data except during read-out when the data is momentarily prevented from changing by driving the inhibit lines to Logic "0", a function performed by the tape formatter (see Figure 12).

Inasmuch as two characters (11 bits) are used for each channel, on tape, the least three significant bits are not presently used. They are unnecessary since the resolution now obtained is very adequate when compared to transducer resolution. However, anytime more resolution is desired, the other three bits can be recorded by reprogramming the tape formatter.

The converters are physically mounted above the digital multiplexer and their ± 15 volt DC power is obtained by a regulated supply mounted on the side of the digital multiplexer.

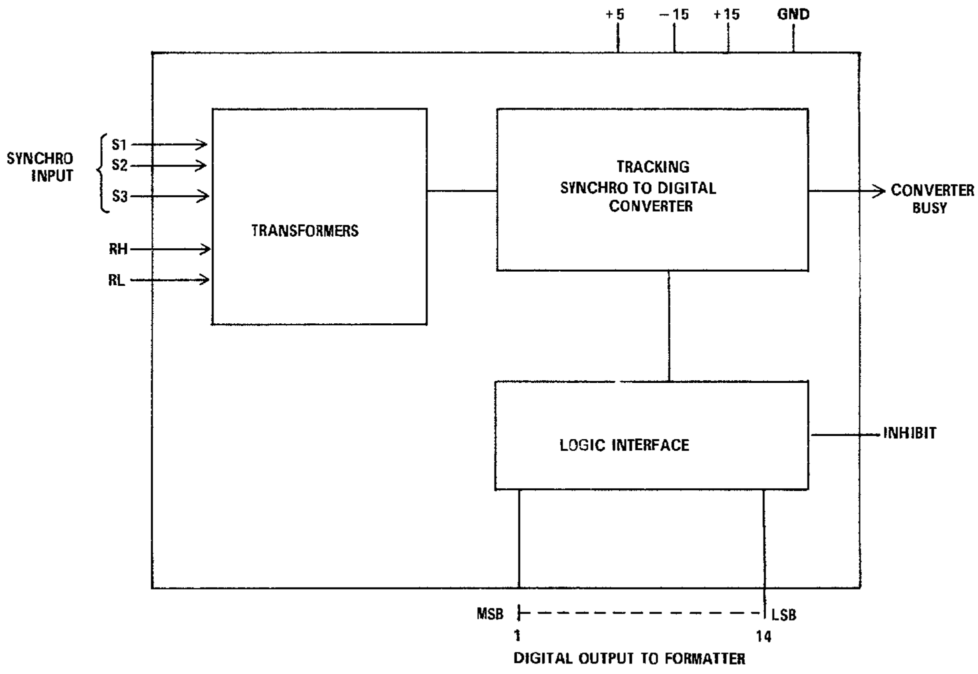


Figure 12

Synchro-To-Digital Converter

C. Filters

All analog signals are fed through low pass filters to eliminate any high frequency noise caused by the helicopter vibration which is picked up by the transducers. This filtering is also used to keep "aliasing" errors below 1% in the A/D conversion. All filters are active and encapsulated. They are seven pole Tchebyscheff with a reject band attenuation greater than -40 db. The f_c stability is ± 0.1%/°C and the input impedance is $\geq$ 1 Meg. ohm.

The three linear acceleration outputs are fed through 2 Hz low pass filters while all others are 5 Hz. These frequencies were selected because of the 20/second sampling rate of the recorder and the peak natural vibration of the UH-1 helicopter which were found to be around 11-12 cycles with some subfrequencies at six cycles.

All of the filters and the ± 15 volt and + 5 volt regulated power supplies are mounted in a chassis box beside the recorder case (see Figure 13).

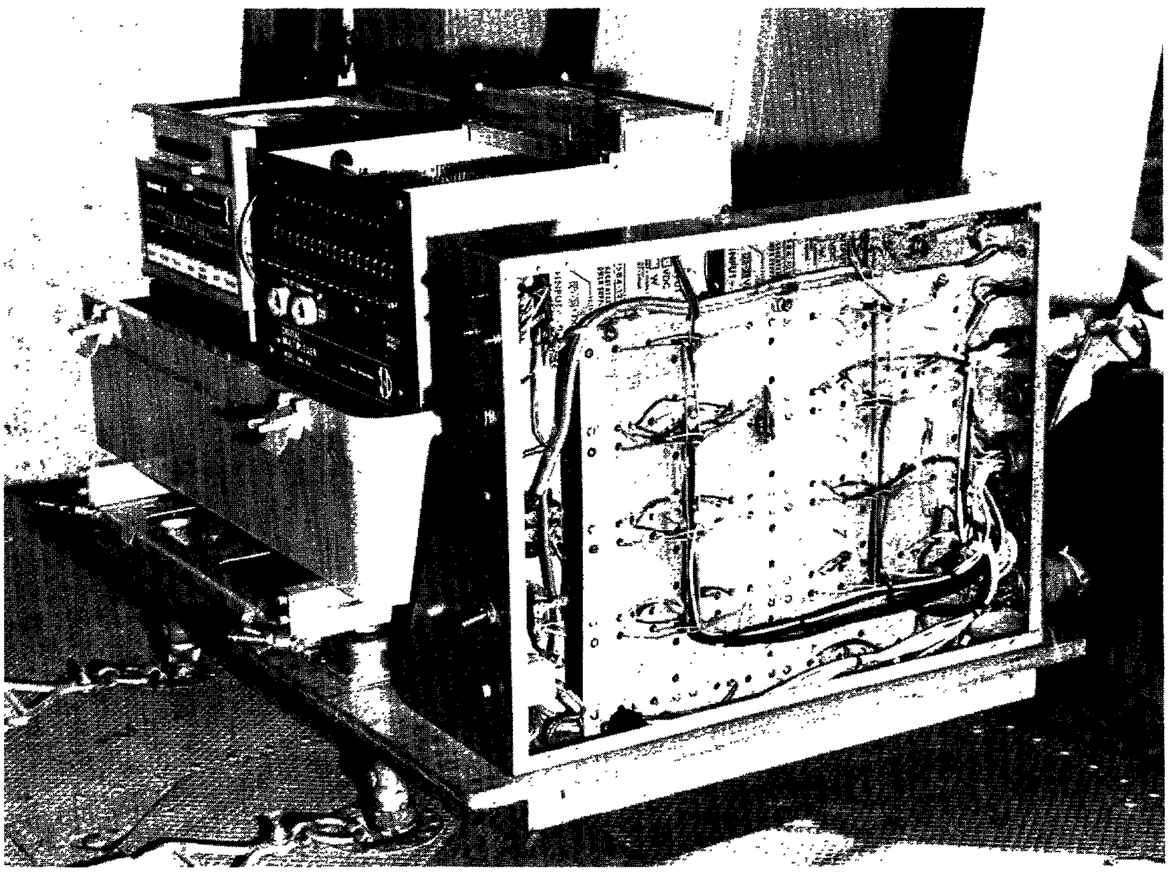


Figure 13

Filters and Power Supplies

DIGITAL RECORDER

A. General

This recorder is an integrated multichannel, mobile data acquisition and recording system. The system is capable of accepting 40 analog data channels and can time divide sequential multiplex, sample and digitize these channels. The system also accepts six bit digital data from external sources.

It time relates either individual data samples or blocks of data through use of an internal digital clock and time code generator. Maximum flexibility of operation is achieved by utilizing a patch connector to format converted analog data, external digital data, internal clock data, and permit programmed system control. The incremental recorder, an integral part of the system, is capable of programmed system synchronized stepping rates from 0 to 1000 characters per second.

The complete system is of ruggedized construction and light enough for field portability and individual handling. In addition, because of the helicopter environment, a special case was designed to house the tape recorder, multiplexer and power supply (see Figure 14). It consists of a dust proof metal container with a heat sink plate which is used to extract heat from the equipment. The heat is conducted through the bottom of the equipment to the plate. From here it is extracted from the bottom by two small blowers. The entire case is mounted on a slide-out Barry mount with four Barry Type H64-AA-30 isolators on each corner. These isolators protect the recorder from high "G" forces which may be produced during autorotation touchdowns. The isolators are bolted to a flat metal base which has four legs. These legs are spaced the same as those on the jump seats in the UH-1D which permits easy installation and removal of the complete package.

The recorder will operate in an environment from 0-70°C, an altitude ranging from 0-40,000 feet, relative humidity 0-95%, vibrations of 2 G's, 20-2,000 cps, and withstand 5 G's in any direction. The recorder installation can be seen in Figure 15.

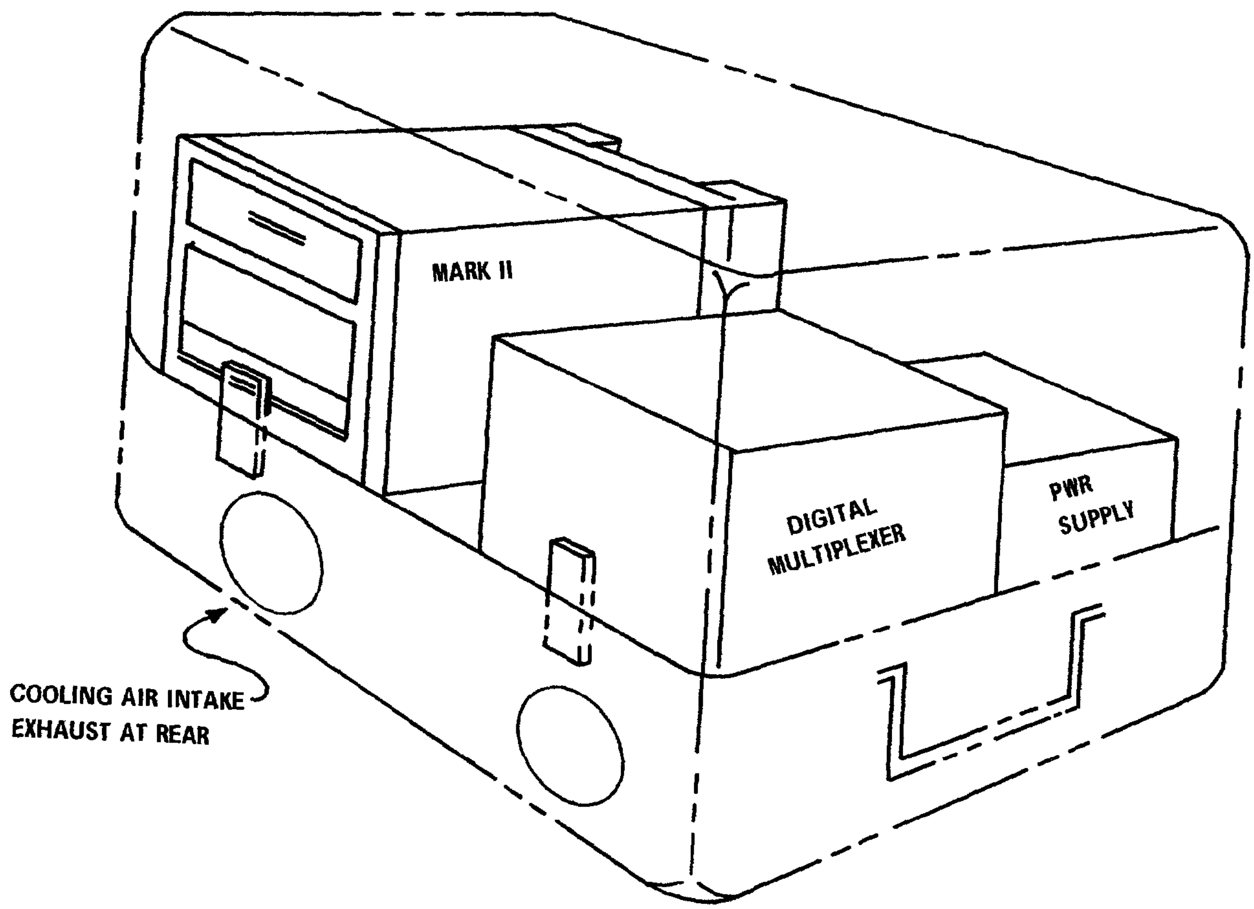


Figure 14

Environmental Case

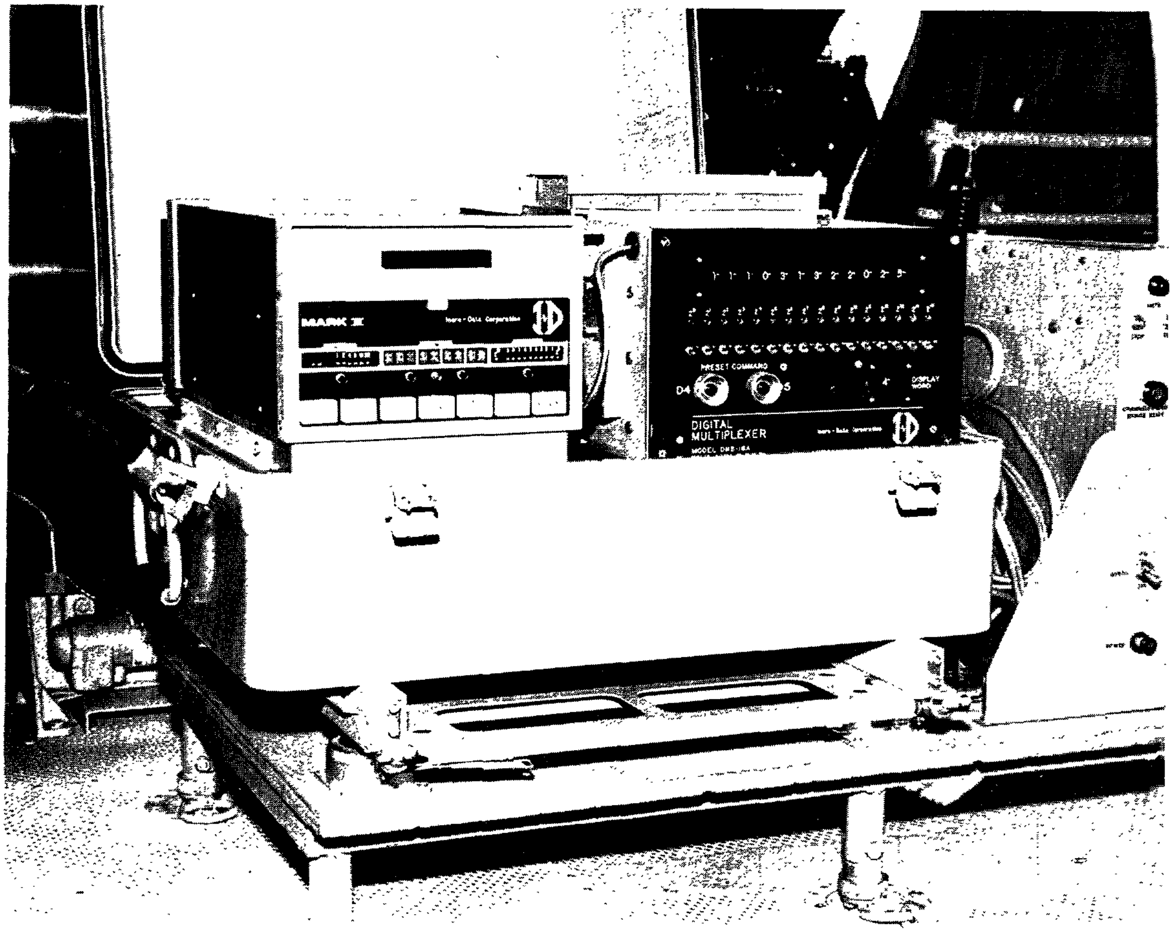


Figure 15

Installed Recorder

B. Incremental Tape Recorder

This recorder operates in a programmed incremental mode which provides a system synchronizer nominal tape advance of .005 inch (200 BPI) for each character step command. Stepped increments occur from a capstan directly driven from the shaft stepping motor at rates of 0-2000 increments per second. This provides a writing rate of 0-1000 characters per second. Currently, it is programmed to write 800 characters per second.

The recorder accepts a single reel cartridge which contains either 1000 feet or 550 feet of 1.5 miltape depending on the cartridge reel hub size used. When loading is initiated, a leader in the machine automatically picks up the tape in the cartridge and loads the tape to the BOT (beginning of tape) marker. The 7-track 200 BPI tape has a skew that is within ± 5% of the character-character spacing. The character density variation is less than 1% at 200 bits/inch. Individual character spacing is within ± 10% of the 200 bit/inch distance. Lateral odd parity and IBM longitudinal redundancy character checks (LRCC) are performed and written. Lateral echo parity is checked with an error signal output available on a rear patch connector. Inter-record gaps (IRG) and end of files (EOF) are standard, being 3/4 inch + 1/8 - 1/15 and 3.4 ± 0.9 inches consecutively. This recorder is capable of rewind in two minutes which permits the expeditious changing of tapes.

C. Tape Format and Programming

The input data and the digital recorder are controlled by the programmable logic found in the recorder and the digital multiplexer. For a description of the data format controls which can be attained, see Appendix A.

In the present configuration, when the "FMTR-START-STOP" button on the recorder is initiated, the phase shift register advances to P7 and subsequently to P8 so that header data can be written (see Figure 16).

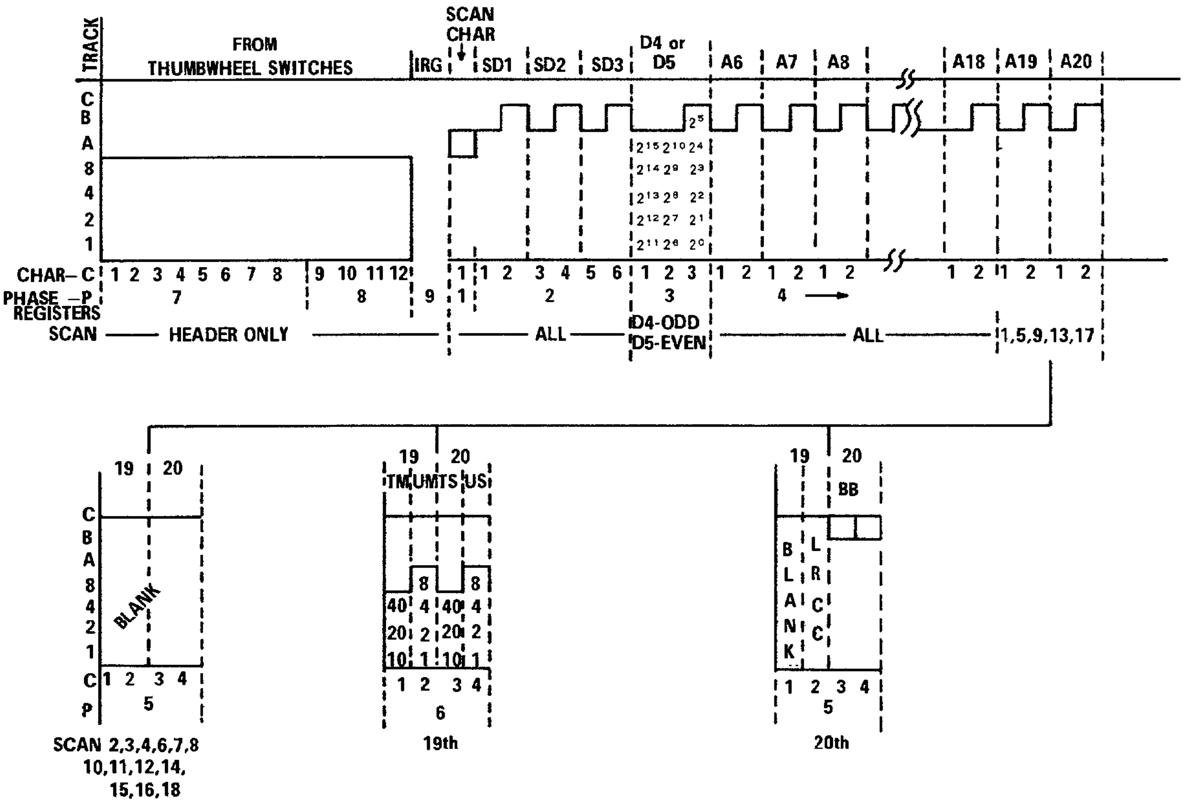


Figure 16

Tape Format

As the phase shift register advances to P9, a one-shot fires and an IRG is generated and the formatter is reset. The following sequence is then started:

A single "A" character is written in P1 which is the scan character and is always an octal 20.

During P2, three two-character words of synchro to digital data, SD1 through SD3 are written. P2 is also used to inhibit the synchro-digital converters so that the synchro data does not change while it is being digitized.

P3 allows a three-character word D4 or D5 to be digitized. D4 is recorded in odd scans 1, 3, 5,.....19 and D5 in even scans 2, 4, 6,.....20.

During P4, thirteen analog words are written. This is increased to fifteen words during scans 1, 5, 9, 13, and 17. During scans 2, 3, 4, 6, 7, 8, 10, 11, 12, 14, 15, 16, and 18 in P5, blank characters are written in the 14th and 15th analog word positions. This is due to the optimal sampling rate determined for barometric altitude and forward airspeed.

In scan 19, time is BCD coded and written in this position in units of seconds and tens of seconds, units of minutes and tens of minutes. In Scan 20, a blank character is written followed by an LRCC character. Following the LRCC are two consecutive "B" bits (octal 40 40) signifying the end of the twentieth scan.

The scan sequence can be seen in Figure 17.

If a STOP command is issued via initiation of the front panel START-STOP switch, recording ceases and an EOF is inserted manually.

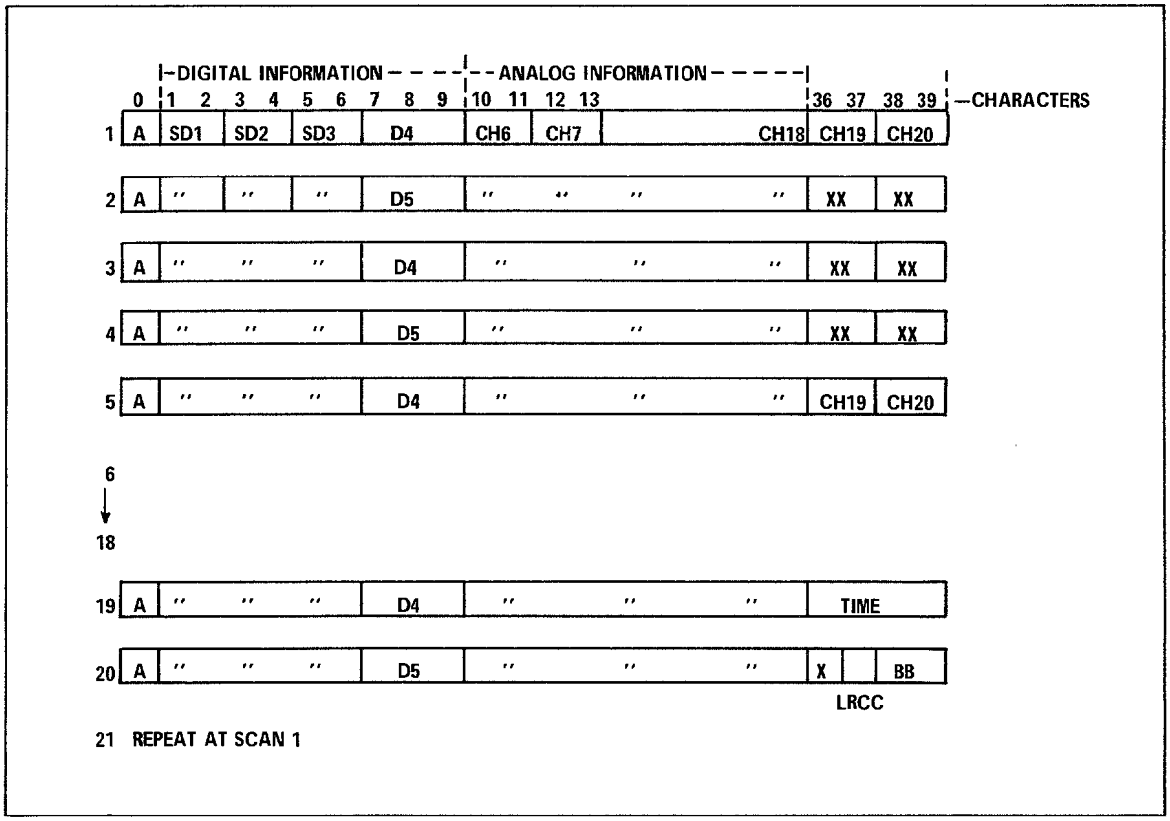


Figure 17

Scan Format

D. Digital Multiplexer

The digital multiplexer is used to gate five digital channels into the recorder. These channels are roll, pitch, heading, and position.

The multiplexer consists of two identical eight binary character cards which accept positive true data from the two counters and the three synchro-digital converters in the multiplexer assembly (see Figure 18).

A control card, takes specifically needed outputs from the recorder programmable logic, signal conditions them via line receivers and line filters, and utilizes the signals as control functions for the multiplexer and the recorder. A DM series unbuffered board binary formats the eleven most significant bits of synchro-digital converter data into a two-character word (SD1-SD3).

A data accumulator consists of a double sixteen bit up-down counter which counts in either an up or down manner depending on the phase of input D4 or D5. Upon the occurrence of P3, the 16 bit word is entered into a buffer register on a multiplexer board, it is then strobed via D4 and D5 from the buffer register and formatted in binary form into a three character word. Toggle switches numbered 2^0 through 2^{15} allow selection of a predetermined word which can be manually strobed into the range counters (D4 or D5).

A binary lamp display used in conjunction with a word display switch indicates D1 through D5 data in binary form. Word 1 through Word 3 is synchro-digital data and fourteen bits are displayed. Word 4 through 5 is range data (D4 and D5) and sixteen bits are displayed.

Tape header data is entered on the beginning of the tape for identification and to program any constant variables for the computer to use during data analysis. This is accomplished by way of twelve thumbwheel switches located on the front panel. The switch outputs are in BCD and controlled by a buffer in the digital multiplexer which feeds the data into the recorder during P7 and P8.

The digital multiplexer is physically located beside the recorder in the environmental case and the heat from it is transferred out the bottom to the case's heat transfer plate.

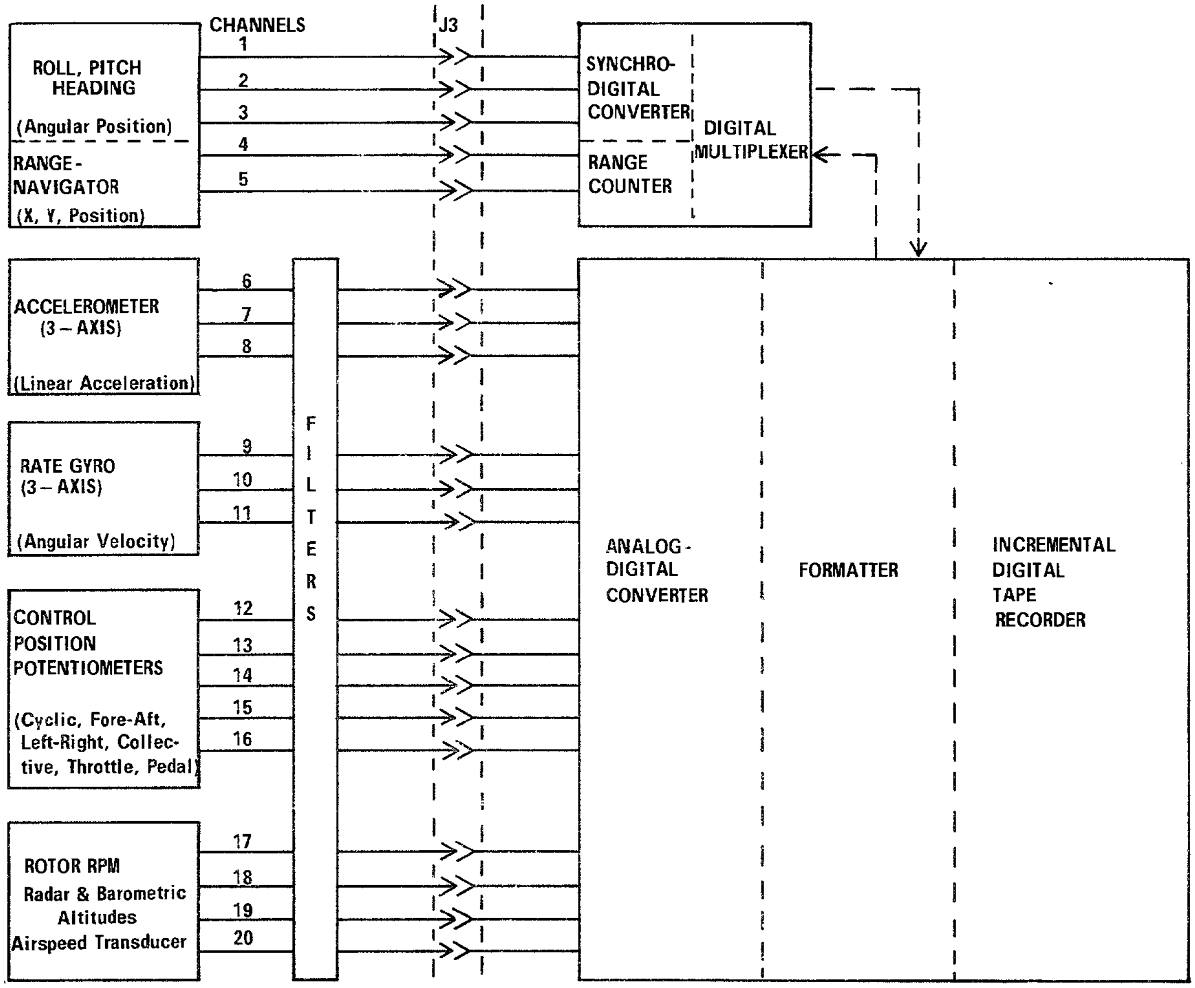


Figure 18

Functional Block Diagram

E. Analog Multiplexer and Analog to Digital Converter

The recorder contains a 40 channel input multiplexer which sequences one channel at a time at rates up to 500 per second with a switching time between channels of less than five microseconds. Each channel is switched through a high impedance MOS/FET network into a track and hold circuit. This circuit tracks the analog channel that is switched on until the next step and record command. This circuit holds the voltage converting it into an 11-bit word through an A/D converter. This word is then written on the tape in two characters at the programmed step and record pulse rate.

The multiplexer switch floats with greater than 40 meg. ohms to ground. Input impedance is that of the track and hold amplifier input when it is less than 50 meg. ohms. The maximum analog input voltage is minus 13 volts to plus 7 volts with normal inputs ranging from 0-5 or ± 2.5 volts. Interchannel crosstalk rejection exceeds 55 db.

The track and hold amplifier has a single ended or differential input impedance greater than 100 meg. ohms. It has a dual channel differential common mode rejection of 10,000/1. The amplifier has a maximum initial offset of .5 millivolt which can be balanced out with a zero adjust on the A/D converter. The offset drift is less than ± 3 microvolts/°C ± 10 microvolts/day and has an initial warm-up drift of less than 20 microvolts and is stable in 10 minutes. It will track an input within .01% in 200 microseconds.

The analog to digital converter provides an 11-bit binary parallel output for recording. It's method of conversion is binary bit successive approximation against an internal reference. Conversion occurs at a step and record pulse time after tracking for a period determined by the programmed multiplexer sequencing rate. The maximum conversion time is 25 microseconds. The A/D converter has a relative accuracy of .01% full scale, ± .001%/°C + 1/2 of the least significant bit.

F. Time Code Generator

An internal time base digitally derived from an oscillator is integrated into the recorder. This digital clock operates from a precision 10 MHz crystal controlled oscillator with an accuracy of ± .1 PPM/°C, ± .01 PPM/day, ± .005 PPM/second. Time counters are provided to allow time correlation of data in milliseconds, seconds, minutes, hours, and day in BCD format. Time is displayed on the front panel in a visual decimal display of day, hours, minutes and seconds. Complete start/stop, presetting and remote control inputs are provided which facilitate both manual and remote control of the time code generator.

SUMMARY OF MEASUREMENTS (DIRECT & DERIVED)

Tables 1, 2, and 3 show the measurements which are now being recorded or derived from HIMS. Also, some of the basic summary statistics being computed for the measurements are given.

TABLE 1

Parameters Measured and Derived Measures

Parameters Measured (Statistics*)	Derived Measures (Statistics*)
Pitch (1-6)	Pitch Rate (1,2,6)
Roll (1-6)	Roll Rate (1,2,6)
Heading (1-6)	Rate of Turn (1-6)
Position x	
Position y (3,4,5)	Ground Speed (1-5)
Acceleration x (6)	
Acceleration y (6)	
Acceleration z (6)	
Roll Rate (6)	Roll Acceleration (6)
Pitch Rate (6)	Pitch Acceleration (6)
Yaw Rate (6)	Yaw Acceleration (6)
Radar Altitude (1-6)	Rate of Climb (1-6)
Barometric Altitude (1-6)	Rate of Climb (1-6)
Airspeed (1-6)	
Flight Time	
Rotor RPM (6)	
Throttle (6)	
Cyclic Stick (Fore-Aft) Cyclic Stick (Left-Right) Collective Pedals	Control Position (1,2,6), Absolute Control Movement Magnitude (1,2,6), Positive Control Movement Magnitude (1,2,6), Negative Control Movement Magnitude (1,2,6), Absolute Average Control Movement Rate (1,2,6), Average Positive Control Movement Rate (1,2,6), Average Negative Control Movement Rate (1,2,6), Control Reversals (7), Instantaneous Control Reversals (7), Control Steady State (7-10), Control Movement (8,9)**

*See Table 2
**See Table 3

TABLE 2

Statistics

1. Mean $\bar{x} = \Sigma \frac{x_i}{n}$

2. Standard Deviation $\sqrt{\frac{\Sigma x^2_i}{n} - \bar{x}^2}$

3. Average Constant Error $\frac{\Sigma(x_i - x_o)}{n}$

4. Average Absolute Error $\frac{\Sigma|x_i - x_o|}{n}$

5. Root Mean Square Error $\sqrt{\frac{\Sigma(x_i - x_o)^2}{n}}$

6. Maximum and Minimum Values

7. Number of Occurrences

8. Total Time in Condition

9. Percent of Total Flight Time in Condition

10. Mean Duration Time

x_o in 3, 4, and 5 are selectable input values

TABLE 3

Control Measures

1. Control Movement - A change in the position of a control over several consecutive readings in one direction.

2. Control Steady State - The period during which the actual control movement and rate of movement are less than predetermined input values.

3. Control Reversal - A change in the direction of movement of a control outside of steady state periods.

4. Instantaneous Control Reversal - A change of control movement direction as computed for consecutive samples.

5. Control Movement Magnitude - $\Delta x = x_{t2} - x_{t1}$

6. Average Control Movement Rate - $\dfrac{\Delta x}{\Delta t} = \dfrac{x_{t2} - x_{t1}}{t2 - t1}$

7. Instantaneous Control Rate - The derivative obtained from a fourth degree equation fitted through five consecutive samples with the desired time at the middle point.

Therefore,

$$\frac{dxt3}{dt} = \frac{20}{12} \left[x_{t1} - x_{t5} - 8\,(x_{t2} - x_{t4})\right]$$

APPENDIX A

Programmable Formatter

The programmable formatter utilizes a patch wire connector located on the rear panel. The system and data format control functions which can be attained through patching are as follows:

1. Twelve stage character shift register which is programmable for generating successive strobe pulses to enter characters into the machine.

2. Character register reset functions such that during each of the phases (words), the character register may be reset from any number 1 through 12, this reset number being capable of being a different number in each phase.

3. Actual data inputs to write flip/flops available for all seven data tracks which includes the internally derived parity bit.

4. Programmable phase or word shift register capable of strobing up to 12 words in sequence.

5. Last phase reset output which allows resetting of the word shift register at any phase from 1 to 12.

6. Multiplexer channel selector register which permits selection of up to 40 single-ended analog input signals or 20 differential analog signal inputs as determined by the manner in which the patch is wired.

7. A last channel output for resetting the sequential multiplexer at the end of the desired total number of input channels.

8. A character cycles per word or multiplexer cycles per word counter for providing multiple cycles of data in one word before sequencing to the next word or phase.

9. A reset output for resetting the multiple cycle counter in 8. above at different cycle counts in each phase or word of data.

10. Step and record command input to cause the character to be written on magnetic tape plus incrementally stepping the tape one space.

11. A separate step and record command for writing time on the tape at a different data rate to allow the full time word to be written within the time limitation of the clock interrupter.

12. Inter-record gap (IRG) command input to command IRG at the desired sequence in the writing of data.

13. An input for commanding a 2-character gapless tape command in that instance where an IRG is not required for those computers capable of reading gapless tape.

14. End of file (EOF) command input to command a standard IBM computer compatible EOF when desired.

15. The following test functions for testing the system:

a. External A/D command to convert signal.

b. Test rate command to advance the formatter a step at a time.

c. External test enable line to enable the machine in the test mode.

d. External test enable for character register, phase register, cycle/phase counter and multiplexer.

e. External test stop to disenable machine.

16. Twelve inputs for gating in each of the 12 internal time characters.

17. Enable time data command for patching in time as required.

18. External formatter reset input to command remote reset of formatter functions when desired externally.

19. A clock start, clock stop and external clock interrupt line to start and stop the clock as determined by external inputs, and to interrupt the clock while clock data is being written on the record. The clock will automatically update at conclusion of the clock interrupt input.

20. Formatter start and stop input lines for starting the formatter and stopping the formatter.

21. Gate input lines to strobe the A/D 11-bit word on the record in two characters of binary information.

22. An input command to enable the A/D data to be written.

23. An input to enable external characters to be written on the record.

24. Enable conversion for time input which takes the first analog channel data and command an analog/digital conversion at the exact instant time is commanded to be written on the tape.

25. Logic input which permits the character cycle per word and multiplexer cycle per word counter to be reset only at the enabling of external characters or time at the proper count patched and will not be active or cause a reset when multiplexer operation is enabled.

26. An input to command the unit to write even lateral parity for those instances where BCD information is being recorded that requires even parity for computer recognition.

27. An input to turn the internal multiplexer off in those instances where an external multiplexer expander circuit is used.

28. An input for commanding dual channel multiplexer switching operation when differential analog input data is being recorded.

29. Output + 5 volt DC voltage and ground return to power additional external TTL logic circuitry.

30. A flag A and flag B input to write bits into channels A and B for data flagging.

31. An output for each of the following functions in the machine:

a. Beginning of tape (BOT).

b. End of tape (EOT).

c. A power on reset signal to external logic.

d. 10 megahertz primary oscillator frequency.

e. 1 megahertz.

f. 100 kilohertz.

g. 1 kilohertz.

h. 2 K PPS.

i. 1 K PPS.

j. Echo line head output for all 7 channels and echo lateral parity error output.

k. Reset or find BOT.

l. Master reset (MR).

m. Ready signal.

n. Formatter running.

o. Write strobe.

p. Advance MUX channel selector signal.

q. Phase or word advance signal for additional external logic.

r. Tape return to cartridge.

s. End IRG.

t. End EOF.

u. Phase cycle complete.

v. Step and record pulse output.

w. IRG pulse output.

x. EOF pulse output.

y. Stop delay pulse output.

32. Time set gate inputs from hundreds of days through units of seconds to allow external time setting of clock.

33. A remote restart clock input.

34. A remote clock set enable function to enable time setting.

35. A remote clock set pulse input for setting time through the time set gate inputs.

36. A 366 day reset line for causing clock to properly reset during leap years.

37. Binary coded decimal outputs from the clock in days through milliseconds. (12 decades)

38. Multiplexer channel being sampled by the A/D converter. (Binary representation)

39. Signal out to indicate clock is running.

40. Status signal indicating the A/D is in the converting process.

41. A reset signal output indicating system reset.

42. A formatter running and stop output to indicate these functions.

43. A remote load line for remote tape loading.

44. A remote load indicator output indicating tape loading is complete.

45. A fast rewind signal to indicate machine rewinding.

46. Remote machine command functions as follows:

    a. Start and stop

    b. Reset

    c. Load

    d. Formatter start

    e. Formatter stop

    f. EOF command

    g. Rewind command

47. Additional programmable logic as follows:

    a. Twelve two-input NAND gates and gate outputs.

    b. Three strobe one-shots with input and normal output plus complementary output.

    c. One binary 10-bit counter with count, reset, and output lines.

    d. One binary 4-bit counter with count, reset and output lines.

    e. One four-input NAND gate with output.

    f. One eight-input NAND gate with output.

    g. Three J-K flip/flops with inputs, outputs and reset circuits.

APPENDIX B

Components by Model and Manufacturer

Parameter	Component	Manufacturer	Model
Airspeed	Differential Pressure Transducer	CIC	6,000
Barometric Altitude	Absolute Pressure Transducer	CIC	7,000
Radar Altitude	Radar Altimeter	Honeywell	AN/APN-198(V)
Linear Acceleration	Triaxial Accelerometer	Humphrey, Inc.	LA-70
Angular Rate	Triaxial Rate Gyro	Humphrey, Inc.	Series RG02
Aircraft Position	Radio Ranging System	Hastings-Raydist	Raydist "T"
Control Position	Potentiometers	TCC	PT101
	Digital Recorder	Incre-Data	Mark II